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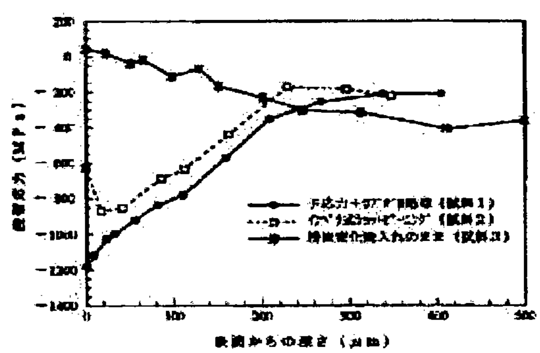
(54) METHOD FOR MODIFYING SURFACE OF STEEL MATERIAL

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a method for modifying the surface of a steel material, which can introduce the maximum compression residual-stress on the top surface of the steel material.

SOLUTION: The objective method for modifying the surface of the steel material comprises hardening the steel material 11, and then subjecting the steel material 11 to subzero treatment in a state of giving the tensile stress P, while giving the tensile stress P to the hardened steel material 11, to introduce the compression residual stress into the steel material 11.



CLAIMS

[Claim(s)]
[Claim 1]A surface modification method of steel materials giving tensile stress to the hardening steel materials after performing hardening treatment to steel materials, and performing subzero treatment to steel materials in the state where tensile stress was given, and introducing compressive residual stress into steel materials.
[Claim 2]After performing hardening treatment to a gear formed with steel materials, insert a shaft of a major diameter in a ring part of the gear rather than an inside diameter of a ring part, give tensile stress to a gear, and. A surface modification method of steel materials performing subzero treatment to a gear in the state where tensile stress was given, and introducing compressive residual stress into a gear.
[Claim 3]A surface modification method of the steel materials according to claim 1 or 2 which perform carburizing treatment or carbonitriding processing to steel materials before performing hardening treatment.

[Translation done.]

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention]This invention relates to the surface modification method of steel materials, and relates to the tooth flank reforming method of the gear especially.
[0002]
[Description of the Prior Art]In recent years, in the machine part for cars which consists of steel materials, for example, the gear, the small weight saving by improvement in fatigue strength (bending especially fatigue strength) is called for from a viewpoint of earth environment and the financial side.
[0003]As a means which raises the fatigue strength of steel materials, improvement in surface part hardness is mentioned first. The improvement in surface part hardness is made by surface treatment processings (carburization, nitriding, soft nitriding, carbonitriding, induction hardening, etc.). When the surface part hardness of steel materials is set to 700 or more HV by surface treatment processing, improvement in surface part hardness stops however, contributing to improvement in fatigue strength. Therefore, introduction of the compressive residual stress which is another means which raises the fatigue strength of steel materials in this case is needed.
[0004]As an introduction means of compressive residual stress, shot peening, laser peening, cavitation peening, etc. are mentioned, and impeller type shot peening is generally used well especially. Here, although it was difficult for hardness to introduce compressive residual stress since the steel materials of 700 or more HV have too high deformation resistance, compressive residual stress can be introduced also into the steel materials of 700 or more HV by performing shot peening, where tensile stress is given.
[0005]
[Problem(s) to be Solved by the Invention]By the way, in order to raise the fatigue strength of steel materials more, it is effective to make it compressive residual stress serve as the maximum in the outermost surface of steel materials.
[0006]However, in the introducing method of the compressive residual stress by shot peening, the position of the maximum compressive residual stress was set to 30-60 micrometers from the surface, and there was a problem that the maximum compressive residual stress could not be obtained in the outermost surface of steel materials. That is, since the compressive residual stress of the outermost surface of steel materials was small, there was a problem that the large improvement in fatigue strength was not expectable.
[0007]If shot peening is performed to steel materials, since the surface roughness of steel materials becomes coarse, the fall of fatigue strength will be caused, and there was a problem that work environment got worse with the noise and the dust which are produced when a shot-grains child collides with steel materials.
[0008]The introducing method of the compressive residual stress by shot peening had the problem that the manufacturing cost of a product became high, as a result from equipment and an installed cost being high.
[0009]The purpose of this invention originated in consideration of the above situation is to provide the surface modification method of the steel materials which can introduce the maximum compressive residual stress into the outermost surface of steel materials.
[0010]
[Means for Solving the Problem]A surface modification method of steel materials applied to this invention that the above-mentioned purpose should be attained gives tensile stress to the hardening steel materials, after performing hardening treatment to steel materials, and performs subzero treatment to steel materials in the state where tensile stress was given, and introduces compressive residual stress into steel materials. After performing hardening treatment to a gear formed with steel materials, insert a shaft of a major diameter in a ring part of the gear rather than an inside diameter of a ring part, and tensile stress is given to a gear, and subzero treatment is performed to a gear in the state where tensile stress was given, and compressive residual stress is introduced into a gear.
[0011]Carburizing treatment or carbonitriding processing may be performed to steel materials before performing hardening treatment.

[0012]According to the surface modification method of the above steel materials, the maximum compressive residual stress can be introduced on the surface of steel materials.
[0013]
[Embodiment of the Invention]Hereafter, the suitable 1 embodiment of this invention is described based on an accompanying drawing.
[0014]If shot peening mentioned above is performed to the steel materials by which hardening treatment was carried out, the retained austenite which exists in steel materials will carry out a phase transformation to martensite, but since it is accompanied by cubical expansion in that case, compressive residual stress is introduced by this cubical expansion. Since the phase transformation of the retained austenite is carried out to martensite even if it replaces with the kinetic energy by shot peening and gives thermal energy here, this invention has the feature at the point which adopted subzero treatment, in order to give thermal energy.
[0015]The surface modification method of the steel materials concerning a 1st embodiment, After giving tensile stress to the hardening steel materials after performing hardening treatment to steel materials, and performing subzero treatment to the steel materials in the state (initial stress state) where tensile stress was given, high compressive residual stress is introduced into steel materials especially on the surface of steel materials by canceling grant of the tensile stress to steel materials. The steel materials said here do not show only a raw material, and steel members are also included.
[0016]As a method of giving tensile stress to hardening steel materials, For example, as shown in drawing 1, arrange the top presser-foot pins 13a and 13b on the upper surface of the plate (steel materials) 11, arrange the lower pins 14a and 14b on the undersurface, and. The tensile stress P is given to the plate 11 by penetrating the plate 11 and the top presser-foot pins 13a and 13b, arranging the clamping bolts 15a and 15b, fixing the plate 11 to the stand 12 with the clamping bolts 15a and 15b, and performing 4 point bendings. At this time, the value of the tensile stress P given to the plate 11 by sticking the strain gage 16 can be checked and adjusted. Subzero treatment is performed fixing the plate 11 to the stand 12.
[0017]Especially if it is the steel materials in which hardening treatment is possible as steel materials, do not limit here, but. Steel materials with much content of retained austenite, i.e., steel materials with much C content, are preferred, for example, carbon tool steel (SK material) of JIS, various alloy-tool-steel steel materials (SKS material, SKD material, SKT material), high-speed-tool-steel steel materials (SKH material), and high-carbon-chromium bearing steel steel materials (SUJ material) are mentioned. In addition, what performed carburizing treatment (or carbonitriding processing) is mentioned to steel materials with few carbon contents, for example, the carbon steels for machine structural use of JIS, (SC material), and various structural steel worker alloy steel steel materials (SCr material, SCN material, SNCM material).
[0018]Although the stress value of the tensile stress given to hardening steel materials is suitably chosen according to the value of the compressive residual stress introduced into the kind of steel materials, and steel materials and is not limited in particular, it is preferred. [of 700 - 1400MPa]
[0019]the treatment temperature of subzero treatment is what is suitably chosen according to the balance of the hardness of steel materials, and toughness into which compressive residual stress was introduced corresponding to the generated amount (after-mentioned) of the martensite considered as a request -- about -- what is necessary is just below 203K (-70 **)
[0020]Next, an operation of this embodiment is explained.
[0021]It is performing subzero treatment to the steel materials after hardening in the surface modification method of this embodiment, The retained austenite which remained in hardening steel materials mostly metamorphoses, martensite generates, and a carbon atom dissolves to supersaturation, cubical expansion happens, and the steel materials (surface treatment steel materials) in which compressive residual stress was introduced are obtained. In the case of this subzero treatment, the steel materials in which still bigger compressive residual stress was introduced by performing subzero treatment where tensile stress is given to the steel materials after hardening (initial stress state) are obtained. It is guessed that this is what is depended on the phenomenon shown below.
[0022]After the body-centered tetragonal c axis which constitutes the martensitic phase to generate from performing subzero treatment where tensile stress is given to the steel materials after hardening has been pulled by one way in ********** and c shaft orientations, the crystal of a martensitic phase is formed. Release of grant of tensile stress will produce big stress in a compression direction to the crystal of the martensitic phase pulled by c shaft orientations after subzero treatment. Big compressive residual stress is introduced into steel materials by this, and serves as fatigue strength, especially steel materials which bent and were excellent in fatigue strength by it. Here, by using what performed hardening treatment after carburizing treatment (or carbonitriding processing) as steel materials after hardening, C content on the surface of steel materials increases by carburizing treatment (or carbonitriding processing), and the amount of retained austenites on the surface of steel materials increases by subsequent hardening treatment. Then, big compressive residual stress can be introduced into the surface portion of steel materials by performing subzero treatment, where tensile

stress is given to the steel materials after this carburization hardening treatment (or carbonitriding hardening treatment), and compressive residual stress serves as the maximum in the outermost surface of steel materials. As a result, the fatigue strength of steel materials can be raised remarkably.
[0023]Introduction of the compressive residual stress in the surface modification method of this embodiment, Since it is not what is depended on the subzero treatment in the state where tensile stress was given, and is depended on shot peening like before, Work environment does not necessarily get worse with the noise or the dust which are produced when the fall of the fatigue strength of saying [that the surface roughness of steel materials becomes coarse], i.e., steel materials, is not necessarily caused and a shot-grains child collides with steel materials.
[0024]The equipment and the installed cost for the subzero treatment in the surface modification method of this embodiment can aim at reduction of the manufacturing cost of surface treatment steel materials (product) from a cheap thing as a result as compared with it of shot peening in the conventional surface modification method.
[0025]Next, other embodiments of this invention are described based on an accompanying drawing.
[0026]The section schematic diagram for explaining the surface modification method of the steel materials concerning a 2nd embodiment is shown in drawing 4 (a) - drawing 4 (c).
[0027]First, the surface modification method of the steel materials concerning a 2nd embodiment performs carburization hardening treatment to the gear 41 formed with steel materials, as shown in drawing 4 (a).
[0028]Next, as shown in drawing 4 (b), rather than the inside diameter of the ring part 41a of the hardening gear 41, the shaft 42 of a major diameter is inserted in the ring part 41a of the hardening gear 41 with a hydraulic press (press fit), and the tensile stress P is given to the diameter direction (the inside of drawing 4 (b) longitudinal direction) of the gear 41. Predetermined time immersion of the gear 41 which was united with this shaft 42 is carried out into about 123-K liquid nitrogen, and subzero treatment is performed.
[0029]Next, it is neglected after pulling up the gear 41 and the shaft 42 out of liquid nitrogen until the gear 41 and the shaft 42 return to ordinary temperature. Then, as it removes [the ring part 41a of the gear 41 to], putting it (pressing out) and the shaft 42 is shown in drawing 4 (c) with a hydraulic press, the surface treatment gear 43 with which the maximum compressive residual stress was introduced into the outermost surface is obtained.
[0030]In the surface modification method of the steel materials of this embodiment, it cannot be overemphasized that the same operation effect as the surface modification method of the steel materials mentioned above is obtained.
[0031]Since the tensile stress P is uniformly given to the gear 41 whole by the shaft 42, big compressive residual stress is introduced into the surface treatment gear 43 whole by it.
[0032]furthermore -- replacing with press fit and burning in a 2nd embodiment, although press fit is performing the unification with the gear 41 and the shaft 42 -- inserting in -- the unification with the gear 41 and the shaft 42 may be performed. By this, the gear 41 can give the big tensile stress P, and big compressive residual stress can be introduced with the surface treatment gear 43.
[0033]As mentioned above, it cannot be overemphasized that an embodiment of the invention is not limited to the embodiment mentioned above, and various things are otherwise assumed.
[0034]
[Example]After performing hot-forging processing to the round bar which consists of Cr-Mo steel (structural steel worker alloy steel steel-materials SCN822H of JIS) and forming in a plate (40 mm in width, 100 mm in length, and 8 mm in thickness), annealing processing is performed to the plate. Then, it is machined into an annealing plate and smooth material (30 mm in width, 90 mm in length, and 5 mm in thickness) is formed.
[0035]To this smooth material, first Hydrocarbon gas atmosphere, the temperature 1203K (930 **), Vacuum carburizing processing is performed on condition of time 1.26ks (21 minutes), and vacuum nitriding treatment is further performed on condition of an N_2+NH_3 gas atmosphere, the temperature 1143K (870 **), and time 1.8ks (30 minutes).
After that was performed.

[0036](Working example 1) The tensile stress of 1000MPa is given using the method shown in drawing 1 to the smooth material after oil quenching, and smooth material is immersed for 900 s (15 minutes) into the liquid nitrogen of 123K with the state (initial stress state) where tensile stress was given, and subzero treatment is performed.
[0037]Smooth material is pulled up out of liquid nitrogen after subzero treatment, and it is neglected until smooth material returns to ordinary temperature. Then, the clamping bolts 15a and 15b are removed, smooth material is removed from the stand 12, and the sample 1 (surface treatment plate) is produced.
[0038](Conventional example 1) To the smooth material after oil quenching, impeller type shot peening is performed and the sample 2 (surface treatment plate) is produced. here -- the various conditions of impeller type shot peening -- 73 m/s and shot distance are 350 mm, and the coverages of about 560 HV and shot speed

is [the diameter of a shot / phi0.8mm and shot hardness / arc height] about 0.5 mmA(s) about 300%.
[0039](Comparative example 1) Let the smooth material still in the state after oil quenching be the sample 3.
[0040]Remaining stress was measured about the samples 1-3. The relation between the residual stress distribution of each sample, i.e., the depth from the surface, (micrometer), and remaining stress (MPa) is shown in drawing 2.
[0041]Here, measurement of remaining stress was performed using minute part X-rays measuring apparatus. After internal remaining stress masked each sample by the window method, it was ground and measured by predetermined Mr. Fukashi by electrolytic polishing. The measuring point of the remaining stress in each sample makes the strain gage 16 the attached position in the sample 1, and the conditions of stress measurement by X-ray, As for the path of the incident-X-ray beam, calculation of 2 mm and stress used the 2 theta-sin ^{2}psi method (psi= 0 degree, 10 degrees, 20 degrees, 30 degrees, 40 degrees), using a Cr-K_{alpha} line as X-rays.
[0042]As shown in drawing 2, in the sample 3 which is still carbonitriding hardening, the remaining stress ($sigma_{rs}$) of the plate surface was about 50 MPa(s), i.e., tensile remaining stress. the maximum compressive residual stress ($sigma_{rmax}$) -- about -- it was -400MPa and the occurrence position was a position whose depth from the surface is about 410 micrometers.
[0043]In the sample 2 which performs surface treatment processing to the sample 3 with impeller type shot peening, $sigma_{rmax}$ was -869MPa and the occurrence position was a position whose depth from the surface is about 20 micrometers. $sigma_{rs}$ of the plate surface was -628MPa.
[0044]On the other hand, in the sample 1 which performs surface treatment processing to the sample 3 by initial stress + subzero treatment, the occurrence position of $sigma_{rmax}$ was a plate surface and $sigma_{rmax}$ was -1179MPa.
[0045]When it bent about each sample and fatigue strength was measured, the bending fatigue strength of the sample 1 which $sigma_{rmax}$ had generated in the plate surface was improving remarkably as compared with the bending fatigue strength of the samples 1 and 2.
[0046]Next, the samples 1-3 were observed using minute part X-rays measuring apparatus, and the amount of retained austenites was measured. Distribution of the retained austenite of each sample, i.e., the relation between the depth (micrometer) from a plate surface and the amount of retained austenites (capacity %), is shown in drawing 3.
[0047]As shown in drawing 3, in the sample 3 which is still carbonitriding hardening, the amount of the maximum retained austenites ($gamma_{Rmax}$) of the amount of retained austenites ($gamma_{Rs}$) of the plate surface was 47.4wt% 27.6wt%.
[0048]In the sample 2, the amount of $gamma_{Rmax}$ of the amount of $gamma_{Rs}$ was 39.6wt% 22.2wt%. This shows that the amount of $gamma_{Rs}$ seldom decreases, even if it performs surface treatment processing by impeller type shot peening.
[0049]On the other hand, in the sample 1, the amount of $gamma_{Rmax}$ of the amount of $gamma_{Rs}$ was 18.3wt% 14.4wt%. By performing surface treatment processing by initial stress + subzero treatment, the amount of $gamma_{Rs}$ decreases greatly, namely, this shows that there are many generated amounts of a martensitic phase. As a result, big compressive residual stress will be introduced in the sample 1.
[0050]
[Effect of the Invention]In short, according to this invention, the following outstanding effects are demonstrated above.
(1) By performing subzero treatment, where tensile stress is given to the steel materials after hardening, the maximum compressive residual stress can be introduced on the surface of steel materials.
(2) By (1), the steel materials excellent in fatigue strength can be obtained.

[Translation done.]

TECHNICAL FIELD

[Field of the Invention]This invention relates to the surface modification method of steel materials, and relates to the tooth flank reforming method of the gear especially.

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PRIOR ART

[Description of the Prior Art]In recent years, in the machine part for cars which consists of steel materials, for example, the gear, the small weight saving by improvement in fatigue strength (bending especially fatigue strength) is called for from a viewpoint of earth environment and the financial side.
[0003]As a means which raises the fatigue strength of steel materials, improvement in surface part hardness is mentioned first. The improvement in surface part hardness is made by surface treatment processings (carburization, nitriding, soft nitriding, carbonitriding, induction hardening, etc.). When the surface part hardness of steel materials is set to 700 or more HV by surface treatment processing, improvement in surface part hardness stops however, contributing to improvement in fatigue strength. Therefore, introduction of the compressive residual stress which is another means which raises the fatigue strength of steel materials in this case is needed.
[0004]As an introduction means of compressive residual stress, shot peening, laser peening, cavitation peening, etc. are mentioned, and impeller type shot peening is generally used well especially. Here, although it was difficult for hardness to introduce compressive residual stress since the steel materials of 700 or more HV have too high deformation resistance, compressive residual stress can be introduced also into the steel materials of 700 or more HV by performing shot peening, where tensile stress is given.

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EFFECT OF THE INVENTION

[Effect of the Invention]In short, according to this invention, the following outstanding effects are demonstrated above.

(1) By performing subzero treatment, where tensile stress is given to the steel materials after hardening, the maximum compressive residual stress can be introduced on the surface of steel materials.

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention]By the way, in order to raise the fatigue strength of steel materials more, it is effective to make it compressive residual stress serve as the maximum in the outermost surface of steel materials.
[0006]However, in the introducing method of the compressive residual stress by shot peening, the position of the maximum compressive residual stress was set to 30-60 micrometers from the surface, and there was a problem that the maximum compressive residual stress could not be obtained in the outermost surface of steel materials. That is, since the compressive residual stress of the outermost surface of steel materials was small, there was a problem that the large improvement in fatigue strength was not expectable.
[0007]If shot peening is performed to steel materials, since the surface roughness of steel materials becomes coarse, the fall of fatigue strength will be caused, and there was a problem that work environment got worse with the noise and the dust which are produced when a shot-grains child collides with steel materials.
[0008]The introducing method of the compressive residual stress by shot peening had the problem that the manufacturing cost of a product became high, as a result from equipment and an installed cost being high.
[0009]The purpose of this invention originated in consideration of the above situation is to provide the surface modification method of the steel materials which can introduce the maximum compressive residual stress into the outermost surface of steel materials.

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MEANS

[Means for Solving the Problem]A surface modification method of steel materials applied to this invention that the above-mentioned purpose should be attained gives tensile stress to the hardening steel materials, after performing hardening treatment to steel materials, and performs subzero treatment to steel materials in the state where tensile stress was given, and introduces compressive residual stress into steel materials. After performing hardening treatment to a gear formed with steel materials, insert a shaft of a major diameter in a ring part of the gear rather than an inside diameter of a ring part, and tensile stress is given to a gear, and subzero treatment is performed to a gear in the state where tensile stress was given, and compressive residual stress is introduced into a gear.
[0011]Carburizing treatment or carbonitriding processing may be performed to steel materials before performing hardening treatment.
[0012]According to the surface modification method of the above steel materials, the maximum compressive residual stress can be introduced on the surface of steel materials.
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[Embodiment of the Invention]Hereafter, the suitable 1 embodiment of this invention is described based on an accompanying drawing.
[0014]If shot peening mentioned above is performed to the steel materials by which hardening treatment was carried out, the retained austenite which exists in steel materials will carry out a phase transformation to martensite, but since it is accompanied by cubical expansion in that case, compressive residual stress is introduced by this cubical expansion. Since the phase transformation of the retained austenite is carried out to martensite even if it replaces with the kinetic energy by shot peening and gives thermal energy here, this invention has the feature at the point which adopted subzero treatment, in order to give thermal energy.
[0015]The surface modification method of the steel materials concerning a 1st embodiment, After giving tensile stress to the hardening steel materials after performing hardening treatment to steel materials, and performing subzero treatment to the steel materials in the state (initial stress state) where tensile stress was given, high compressive residual stress is introduced into steel materials especially on the surface of steel materials by canceling grant of the tensile stress to steel materials. The steel materials said here do not show only a raw material, and steel members are also included.
[0016]As a method of giving tensile stress to hardening steel materials, For example, as shown in drawing 1, arrange the top presser-foot pins 13a and 13b on the upper surface of the plate (steel materials) 11, arrange the lower pins 14a and 14b on the undersurface, and. The tensile stress P is given to the plate 11 by penetrating the plate 11 and the top presser-foot pins 13a and 13b, arranging the clamping bolts 15a and 15b, fixing the plate 11 to the stand 12 with the clamping bolts 15a and 15b, and performing 4 point bendings. At this time, the value of the tensile stress P given to the plate 11 by sticking the strain gage 16 can be checked and adjusted. Subzero treatment is performed fixing the plate 11 to the stand 12.
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[0018]Although the stress value of the tensile stress given to hardening steel materials is suitably chosen according to the value of the compressive residual stress introduced into the kind of steel materials, and steel materials and is not limited in particular, it is preferred. [of 700 - 1400MPa]
[0019]the treatment temperature of subzero treatment is what is suitably chosen according to the balance of the hardness of steel materials, and toughness into which compressive residual stress was introduced corresponding to the generated amount (after-mentioned) of the martensite considered as a request -- about -

- what is necessary is just below 203K (-70 **)
[0020]Next, an operation of this embodiment is explained.
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[0022]After the body-centered tetragonal c axis which constitutes the martensitic phase to generate from performing subzero treatment where tensile stress is given to the steel materials after hardening has been pulled by one way in ********** and c shaft orientations, the crystal of a martensitic phase is formed. Release of grant of tensile stress will produce big stress in a compression direction to the crystal of the martensitic phase pulled by c shaft orientations after subzero treatment. Big compressive residual stress is introduced into steel materials by this, and serves as fatigue strength, especially steel materials which bent and were excellent in fatigue strength by it. Here, by using what performed hardening treatment after carburizing treatment (or carbonitriding processing) as steel materials after hardening, C content on the surface of steel materials increases by carburizing treatment (or carbonitriding processing), and the amount of retained austenites on the surface of steel materials increases by subsequent hardening treatment. Then, big compressive residual stress can be introduced into the surface portion of steel materials by performing subzero treatment, where tensile stress is given to the steel materials after this carburization hardening treatment (or carbonitriding hardening treatment), and compressive residual stress serves as the maximum in the outermost surface of steel materials. As a result, the fatigue strength of steel materials can be raised remarkably.
[0023]Introduction of the compressive residual stress in the surface modification method of this embodiment, Since it is not what is depended on the subzero treatment in the state where tensile stress was given, and is depended on shot peening like before, Work environment does not necessarily get worse with the noise or the dust which are produced when the fall of the fatigue strength of saying [that the surface roughness of steel materials becomes coarse], i.e., steel materials, is not necessarily caused and a shot-grains child collides with steel materials.
[0024]The equipment and the installed cost for the subzero treatment in the surface modification method of this embodiment can aim at reduction of the manufacturing cost of surface treatment steel materials (product) from a cheap thing as a result as compared with it of shot peening in the conventional surface modification method.
[0025]Next, other embodiments of this invention are described based on an accompanying drawing.
[0026]The section schematic diagram for explaining the surface modification method of the steel materials concerning a 2nd embodiment is shown in drawing 4 (a) - drawing 4 (c).
[0027]First, the surface modification method of the steel materials concerning a 2nd embodiment performs carburization hardening treatment to the gear 41 formed with steel materials, as shown in drawing 4 (a).
[0028]Next, as shown in drawing 4 (b), rather than the inside diameter of the ring part 41a of the hardening gear 41, the shaft 42 of a major diameter is inserted in the ring part 41a of the hardening gear 41 with a hydraulic press (press fit), and the tensile stress P is given to the diameter direction (the inside of drawing 4 (b) longitudinal direction) of the gear 41. Predetermined time immersion of the gear 41 which was united with this shaft 42 is carried out into about 123-K liquid nitrogen, and subzero treatment is performed.
[0029]Next, it is neglected after pulling up the gear 41 and the shaft 42 out of liquid nitrogen until the gear 41 and the shaft 42 return to ordinary temperature. Then, as it removes [the ring part 41a of the gear 41 to], putting it (pressing out) and the shaft 42 is shown in drawing 4 (c) with a hydraulic press, the surface treatment gear 43 with which the maximum compressive residual stress was introduced into the outermost surface is obtained.
[0030]In the surface modification method of the steel materials of this embodiment, it cannot be overemphasized that the same operation effect as the surface modification method of the steel materials mentioned above is obtained.
[0031]Since the tensile stress P is uniformly given to the gear 41 whole by the shaft 42, big compressive residual stress is introduced into the surface treatment gear 43 whole by it.
[0032]furthermore -- replacing with press fit and burning in a 2nd embodiment, although press fit is performing the unification with the gear 41 and the shaft 42 -- inserting in -- the unification with the gear 41 and the shaft 42 may be performed. By this, the gear 41 can give the big tensile stress P, and big compressive residual stress can be introduced with the surface treatment gear 43.
[0033]As mentioned above, it cannot be overemphasized that an embodiment of the invention is not limited to the embodiment mentioned above, and various things are otherwise assumed.

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EXAMPLE

[Example]After performing hot-forging processing to the round bar which consists of Cr-Mo steel (structural steel worker alloy steel steel-materials SCN822H of JIS) and forming in a plate (40 mm in width, 100 mm in length, and 8 mm in thickness), annealing processing is performed to the plate. Then, it is machined into an annealing plate and smooth material (30 mm in width, 90 mm in length, and 5 mm in thickness) is formed.
[0035]To this smooth material, first Hydrocarbon gas atmosphere, the temperature 1203K (930 **), Vacuum carburizing processing is performed on condition of time 1.26ks (21 minutes), and vacuum nitriding treatment is further performed on condition of an N_2+NH_3 gas atmosphere, the temperature 1143K (870 **), and time 1.8ks (30 minutes).
After that was performed.

[0036](Working example 1) The tensile stress of 1000MPa is given using the method shown in drawing 1 to the smooth material after oil quenching, and smooth material is immersed for 900 s (15 minutes) into the liquid nitrogen of 123K with the state (initial stress state) where tensile stress was given, and subzero treatment is performed.
[0037]Smooth material is pulled up out of liquid nitrogen after subzero treatment, and it is neglected until smooth material returns to ordinary temperature. Then, the clamping bolts 15a and 15b are removed, smooth material is removed from the stand 12, and the sample 1 (surface treatment plate) is produced.
[0038](Conventional example 1) To the smooth material after oil quenching, impeller type shot peening is performed and the sample 2 (surface treatment plate) is produced. here -- the various conditions of impeller type shot peening -- 73 m/s and shot distance are 350 mm, and the coverages of about 560 HV and shot speed is [the diameter of a shot / phi0.8mm and shot hardness / arc height] about 0.5 mmA(s) about 300%.
[0039](Comparative example 1) Let the smooth material still in the state after oil quenching be the sample 3.
[0040]Remaining stress was measured about the samples 1-3. The relation between the residual stress distribution of each sample, i.e., the depth from the surface, (micrometer), and remaining stress (MPa) is shown in drawing 2.
[0041]Here, measurement of remaining stress was performed using minute part X-rays measuring apparatus. After internal remaining stress masked each sample by the window method, it was ground and measured by predetermined Mr. Fukashi by electrolytic polishing. The measuring point of the remaining stress in each sample makes the strain gage 16 the attached position in the sample 1, and the conditions of stress measurement by X-ray, As for the path of the incident-X-ray beam, calculation of 2 mm and stress used the 2 theta-sin ^{2}psi method (psi= 0 degree, 10 degrees, 20 degrees, 30 degrees, 40 degrees), using a Cr-K_{alpha} line as X-rays.
[0042]As shown in drawing 2, in the sample 3 which is still carbonitriding hardening, the remaining stress ($sigma_{rs}$) of the plate surface was about 50 MPa(s), i.e., tensile remaining stress. the maximum compressive residual stress ($sigma_{rmax}$) -- about -- it was -400MPa and the occurrence position was a position whose depth from the surface is about 410 micrometers.
[0043]In the sample 2 which performs surface treatment processing to the sample 3 with impeller type shot peening, $sigma_{rmax}$ was -869MPa and the occurrence position was a position whose depth from the surface is about 20 micrometers. $sigma_{rs}$ of the plate surface was -628MPa.
[0044]On the other hand, in the sample 1 which performs surface treatment processing to the sample 3 by initial stress + subzero treatment, the occurrence position of $sigma_{rmax}$ was a plate surface and $sigma_{rmax}$ was -1179MPa.
[0045]When it bent about each sample and fatigue strength was measured, the bending fatigue strength of the sample 1 which $sigma_{rmax}$ had generated in the plate surface was improving remarkably as compared with the bending fatigue strength of the samples 1 and 2.
[0046]Next, the samples 1-3 were observed using minute part X-rays measuring apparatus, and the amount of

retained austenites was measured. Distribution of the retained austenite of each sample, i.e., the relation between the depth (micrometer) from a plate surface and the amount of retained austenites (capacity %), is shown in drawing 3.

[0047]As shown in drawing 3, in the sample 3 which is still carbonitriding hardening, the amount of the maximum retained austenites (gamma$_{Rmax}$) of the amount of retained austenites (gamma$_{Rs}$) of the plate surface was 47.4wt% 27.6wt%.

[0048]In the sample 2, the amount of gamma$_{Rmax}$ of the amount of gamma$_{Rs}$ was 39.6wt% 22.2wt%. This shows that the amount of gamma$_{Rs}$ seldom decreases, even if it performs surface treatment processing by impeller type shot peening.

[0049]On the other hand, in the sample 1, the amount of gamma$_{Rmax}$ of the amount of gamma$_{Rs}$ was 18.3wt% 14.4wt%. By performing surface treatment processing by initial stress + subzero treatment, the amount of gamma$_{Rs}$ decreases greatly, namely, this shows that there are many generated amounts of a martensitic phase. As a result, big compressive residual stress will be introduced in the sample 1.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1]It is a surface modification method of the steel materials concerning a 1st embodiment, and is a section schematic diagram showing how to give tensile stress to hardening steel materials.
[Drawing 2]It is a figure showing the relation between the depth from the surface of steel materials, and remaining stress.
[Drawing 3]It is a figure showing the relation between the depth from the surface of steel materials, and the amount of retained austenites.
[Drawing 4]It is a section schematic diagram for explaining the surface modification method of the steel materials concerning a 2nd embodiment.
[Description of Notations]
11 Plate (steel materials)
P Tensile stress

[Translation done.]

* NOTICES *

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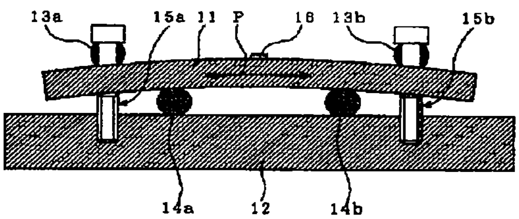
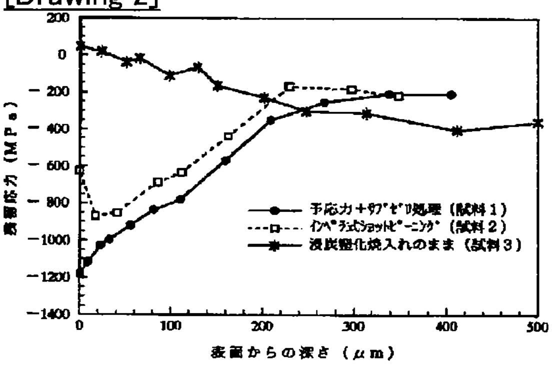
3.In the drawings, any words are not translated.

DRAWINGS

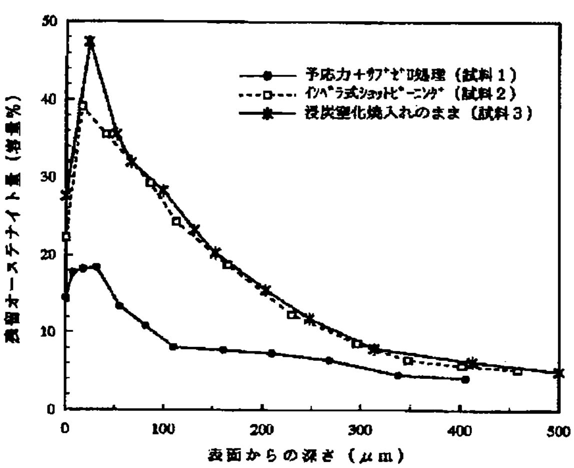
[Drawing 1]



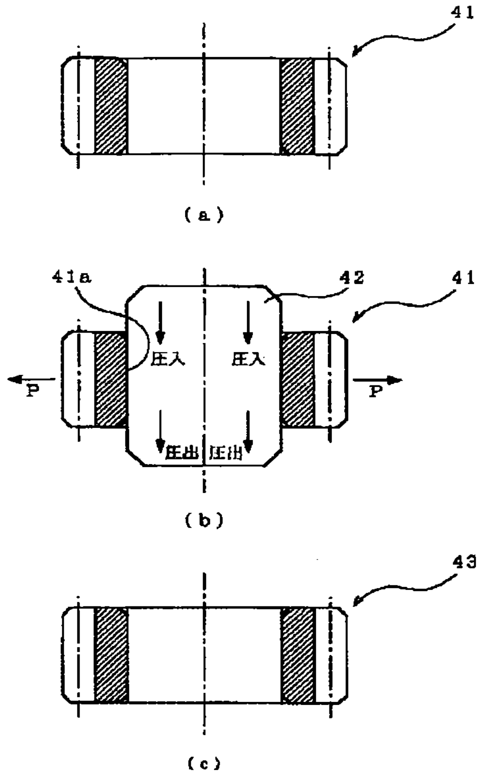
[Drawing 2]



[Drawing 3]



[Drawing 4]



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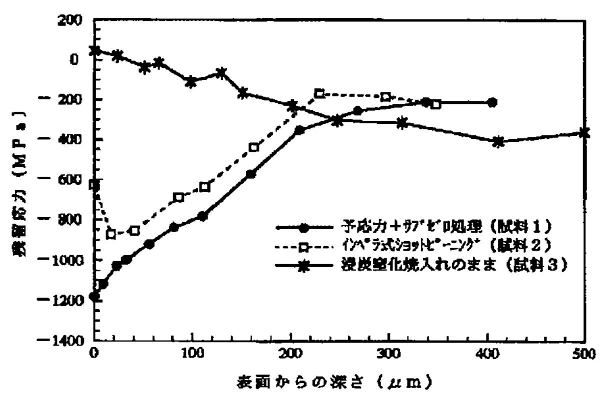
(54)【発明の名称】　鋼材の表面改質方法

(57)【要約】
【課題】　鋼材の最表面に最大圧縮残留応力を導入可能な鋼材の表面改質方法を提供するものである。
【解決手段】　本発明に係る鋼材の表面改質方法は、鋼材１１に焼入れ処理を施した後、その焼入れ鋼材１１に引張応力Ｐを付与すると共に、引張応力Ｐを付与した状態の鋼材１１にサブゼロ処理を施し、鋼材１１に圧縮残留応力を導入するものである。



【特許請求の範囲】

【請求項１】　鋼材に焼入れ処理を施した後、その焼入れ鋼材に引張応力を付与すると共に、引張応力を付与した状態の鋼材にサブゼロ処理を施し、鋼材に圧縮残留応力を導入することを特徴とする鋼材の表面改質方法。

【請求項２】　鋼材で形成した歯車に焼入れ処理を施した後、その歯車のリング部にリング部の内径よりも大径のシャフトを挿入して、歯車に引張応力を付与すると共に、引張応力を付与した状態の歯車にサブゼロ処理を施し、歯車に圧縮残留応力を導入することを特徴とする鋼材の表面改質方法。

【請求項３】　焼入れ処理を施す前の鋼材に、浸炭処理又は浸炭窒化処理を施す請求項１または２記載の鋼材の表面改質方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、鋼材の表面改質方法に係り、特に、歯車の歯面改質方法に関するものである。

【０００２】

【従来の技術】近年、地球環境及び経済面の観点から、鋼材からなる自動車用機械部品、例えば歯車においては、疲労強度（特に、曲げ疲労強度）の向上による小型軽量化が求められている。

【０００３】鋼材の疲労強度を向上させる手段として、先ず、表面部硬さの向上が挙げられる。表面部硬さの向上は、表面改質処理（浸炭、窒化、軟窒化、浸炭窒化、高周波焼入れ等）によりなされる。ところが、表面改質処理により鋼材の表面部硬さが７００ＨＶ以上になると、表面部硬さの向上が疲労強度の向上に寄与しなくなる。よって、この場合、鋼材の疲労強度を向上させる別の手段である圧縮残留応力の導入が必要となる。

【０００４】圧縮残留応力の導入手段としては、ショットピーニング、レーザーピーニング、キャビテーションピーニング等が挙げられ、なかでもインペラ式ショットピーニングが一般的によく用いられている。ここで、硬さが７００ＨＶ以上の鋼材は、変形抵抗が高すぎるため圧縮残留応力を導入することは困難であったが、引張応力を付与した状態でショットピーニングを行うことで、７００ＨＶ以上の鋼材にも圧縮残留応力を導入することができる。

【０００５】

【発明が解決しようとする課題】ところで、鋼材の疲労強度をより向上させるためには、鋼材の最表面で圧縮残留応力が最大となるようにするのが有効である。

【０００６】しかし、ショットピーニングによる圧縮残留応力の導入方法では、最大圧縮残留応力の位置が表面から３０～６０μｍになってしまい、鋼材の最表面において最大圧縮残留応力を得ることができないという問題があった。つまり、鋼材の最表面の圧縮残留応力が小さいため、疲労強度の大幅な向上を期待できないという問題があった。

【０００７】また、鋼材にショットピーニングを施すと、鋼材の表面粗さが粗くなることから、疲労強度の低下を招いてしまうと共に、鋼材にショット粒子が衝突する時に生じる騒音や粉塵によって作業環境が悪化するという問題があった。

【０００８】さらに、ショットピーニングによる圧縮残留応力の導入方法は、設備・建設コストが高いことから、結果的に、製品の製造コストが高くなるという問題があった。

【０００９】以上の事情を考慮して創案された本発明の目的は、鋼材の最表面に最大圧縮残留応力を導入可能な鋼材の表面改質方法を提供することにある。

【００１０】

【課題を解決するための手段】上記目的を達成すべく本発明に係る鋼材の表面改質方法は、鋼材に焼入れ処理を施した後、その焼入れ鋼材に引張応力を付与すると共に、引張応力を付与した状態の鋼材にサブゼロ処理を施し、鋼材に圧縮残留応力を導入するものである。また、鋼材で形成した歯車に焼入れ処理を施した後、その歯車のリング部にリング部の内径よりも大径のシャフトを挿入して、歯車に引張応力を付与すると共に、引張応力を付与した状態の歯車にサブゼロ処理を施し、歯車に圧縮残留応力を導入するものである。

【００１１】また、焼入れ処理を施す前の鋼材に、浸炭処理又は浸炭窒化処理を施してもよい。

【００１２】以上の鋼材の表面改質方法によれば、鋼材の表面に最大圧縮残留応力を導入することができる。

【００１３】

【発明の実施の形態】以下、本発明の好適一実施の形態を添付図面に基いて説明する。

【００１４】前述したショットピーニングを焼入れ処理された鋼材に施すと、鋼材に存在する残留オーステナイトがマルテンサイトに相変態するが、その際に体積膨張を伴うので、この体積膨張によっても圧縮残留応力が導入される。ここで、ショットピーニングによる運動エネルギーに代えて熱エネルギーを与えても、残留オーステナイトはマルテンサイトに相変態するので、本発明は熱エネルギーを与えるためにサブゼロ処理を採用した点に特長を有している。

【００１５】第１の実施の形態に係る鋼材の表面改質方法は、鋼材に焼入れ処理を施した後、その焼入れ鋼材に引張応力を付与すると共に、引張応力を付与した状態（予応力状態）の鋼材にサブゼロ処理を施した後、鋼材への引張応力の付与を解除することで、鋼材に、特に鋼材の表面に高い圧縮残留応力を導入するものである。ここで言う鋼材とは、素材のみを示すものではなく、鋼製の部材も含んでいる。

【００１６】焼入れ鋼材に引張応力を付与する方法とし

ては、例えば、図１に示すように、板材（鋼材）１１の上面に上部押さえピン１３ａ，１３ｂを、下面に下部ピン１４ａ，１４ｂを配置すると共に、板材１１及び上部押さえピン１３ａ，１３ｂを貫通して締付けボルト１５ａ，１５ｂを配置し、締付けボルト１５ａ，１５ｂにより板材１１を台１２に固定し４点曲げを行うことで、板材１１に引張応力Ｐが付与される。この時、板材１１に歪みゲージ１６を貼り付けておくことで、付与される引張応力Ｐの値を確認・調整することができる。サブゼロ処理は、板材１１を台１２に固定したまま行う。

【００１７】ここで、鋼材としては、焼入れ処理が可能な鋼材であれば特に限定するものではないが、残留オーステナイトの含有量が多い鋼材、即ちＣ含有量が多い鋼材が好ましく、例えばＪＩＳ規格の炭素工具鋼鋼材（SK材）、各種合金工具鋼鋼材（SKS材，SKD材，SKT材）、高速度工具鋼鋼材（SKH材）、高炭素クロム軸受鋼鋼材（SUJ材）が挙げられる。この他にも、炭素含有量の少ない鋼材、例えばＪＩＳ規格の機械構造用炭素鋼鋼材（SC材）又は各種構造用合金鋼鋼材（SCr材、SCM材、SNCM材）に、浸炭処理（又は浸炭窒化処理）を施したものが挙げられる。

【００１８】焼入れ鋼材に付与する引張応力の応力値は、鋼材の種類及び鋼材に導入する圧縮残留応力の値に応じて適宜選択されるものであり、特に限定するものではないが、７００～１４００ＭＰａが好ましい。

【００１９】サブゼロ処理の処理温度は、所望とするマルテンサイトの生成量（後述）に応じて、即ち圧縮残留応力が導入された鋼材の硬度及び靭性のバランスに応じて適宜選択されるものであり、約２０３Ｋ（－７０℃）以下であればよい。

【００２０】次に、本実施の形態の作用を説明する。

【００２１】本実施の形態の表面改質方法においては、焼入れ後の鋼材にサブゼロ処理を施すことで、焼入れ鋼材に多く残存していた残留オーステナイトが変態してマルテンサイトが生成すると共に、炭素原子が過飽和に固溶されて体積膨張が起こり、圧縮残留応力が導入された鋼材（表面改質鋼材）が得られる。また、このサブゼロ処理の際、焼入れ後の鋼材に引張応力を付与した状態（予応力状態）でサブゼロ処理を行うことで、更に大きな圧縮残留応力が導入された鋼材が得られる。これは、以下に示す現象によるものと推測される。

【００２２】焼入れ後の鋼材に引張応力を付与した状態でサブゼロ処理を行うことで、生成するマルテンサイト相を構成する体心正方晶のｃ軸が一方向に引揃えられ、かつ、ｃ軸方向に引張られた状態でマルテンサイト相の結晶が形成される。サブゼロ処理後、引張応力の付与を解除すると、ｃ軸方向に引張られていたマルテンサイト相の結晶に対して圧縮方向に大きな応力が生じる。これによって、大きな圧縮残留応力が鋼材に導入され、疲労強度、特に曲げ疲労強度に優れた鋼材となる。ここで、焼入れ後の鋼材として、浸炭処理（又は浸炭窒化処理）後に焼入れ処理を施したものを用いることで、浸炭処理（又は浸炭窒化処理）により鋼材表面のＣ含有量が多くなり、その後の焼入れ処理により鋼材表面の残留オーステナイト量が多くなる。その後、この浸炭焼入れ処理（又は浸炭窒化焼入れ処理）後の鋼材に、引張応力を付与した状態でサブゼロ処理を行うことで、鋼材の表面部分に大きな圧縮残留応力を導入することができ、鋼材の最表面で圧縮残留応力が最大となる。その結果、鋼材の疲労強度を著しく向上させることができる。

【００２３】また、本実施の形態の表面改質方法における圧縮残留応力の導入は、引張応力を付与した状態でのサブゼロ処理によるものであり、従来のようにショットピーニングによるものではないため、鋼材の表面粗さが粗くなるということ、即ち鋼材の疲労強度の低下を招くということはなく、また、鋼材にショット粒子が衝突する時に生じる騒音や粉塵によって作業環境が悪化するということもない。

【００２４】さらに、本実施の形態の表面改質方法におけるサブゼロ処理のための設備・建設コストは、従来の表面改質方法におけるショットピーニングのそれと比較して安価であることから、その結果、表面改質鋼材（製品）の製造コストの低減を図ることができる。

【００２５】次に、本発明の他の実施の形態を添付図面に基いて説明する。

【００２６】第２の実施の形態に係る鋼材の表面改質方法を説明するための断面概略図を図４（ａ）～図４（ｃ）に示す。

【００２７】第２の実施の形態に係る鋼材の表面改質方法は、先ず、図４（ａ）に示すように、鋼材で形成した歯車４１に浸炭焼入れ処理を施す。

【００２８】次に、図４（ｂ）に示すように、焼入れ歯車４１のリング部４１ａの内径よりも大径のシャフト４２を、油圧プレスにより焼入れ歯車４１のリング部４１ａに挿入（圧入）し、歯車４１の径方向（図４（ｂ）中では左右方向）に引張応力Ｐを付与する。このシャフト４２と一体になった歯車４１を、約１２３Ｋの液体窒素中に所定時間浸漬してサブゼロ処理を施す。

【００２９】次に、歯車４１及びシャフト４２を液体窒素中から引き上げた後、歯車４１及びシャフト４２が常温に戻るまで放置する。その後、油圧プレスによりシャフト４２を歯車４１のリング部４１ａから圧力をかけて取り外し（圧出し）、図４（ｃ）に示すように、最表面に最大圧縮残留応力が導入された表面改質歯車４３が得られる。

【００３０】本実施の形態の鋼材の表面改質方法においても、前述した鋼材の表面改質方法と同様の作用効果が得られることは言うまでもない。

【００３１】また、シャフト４２によって、歯車４１全体に均等に引張応力Ｐが付与されるので、表面改質歯車

４３全体に大きな圧縮残留応力が導入される。

【００３２】さらに、第２の実施の形態においては、圧入により歯車４１とシャフト４２との一体化を行っているが、圧入に代えて焼き嵌めにより歯車４１とシャフト４２との一体化を行ってもよい。これによって、歯車４１により大きな引張応力Ｐを付与することができ、表面改質歯車４３により大きな圧縮残留応力を導入することができる。

【００３３】以上、本発明の実施の形態は、上述した実施の形態に限定されるものではなく、他にも種々のものが想定されることは言うまでもない。

【００３４】

【実施例】Ｃｒ－Ｍｏ鋼（ＪＩＳ規格の構造用合金鋼鋼材SCM822H）からなる丸棒に熱間鍛造処理を施して幅４０ｍｍ、長さ１００ｍｍ、厚さ８ｍｍの板材に形成した後、その板材に焼きなまし処理を施す。その後、焼きなまし板材に機械加工を施し、幅３０ｍｍ、長さ９０ｍｍ、厚さ５ｍｍの平滑材を形成する。

【００３５】この平滑材に対して、先ず、炭化水素ガス雰囲気、温度１２０３Ｋ（９３０℃）、時間１．２６ｋｓ（２１分）の条件で真空浸炭処理を施し、さらに、N_2＋NH_3ガス雰囲気、温度１１４３Ｋ（８７０℃）、時間１．８ｋｓ（３０分）の条件で真空窒化処理を施し、その後、油冷を行った。

【００３６】（実施例１）油冷後の平滑材に対して、図１に示した方法を用いて１０００ＭＰａの引張応力を付与すると共に、引張応力を付与した状態（予応力状態）のまま平滑材を１２３Ｋの液体窒素中に９００ｓ（１５分）浸漬し、サブゼロ処理を施す。

【００３７】サブゼロ処理後、平滑材を液体窒素中から引き上げ、平滑材が常温に戻るまで放置する。その後、締付けボルト１５ａ，１５ｂを取り外して平滑材を台１２から取り外し、試料１（表面改質板材）を作製する。

【００３８】（従来例１）油冷後の平滑材に対して、インペラ式ショットピーニングを施し、試料２（表面改質板材）を作製する。ここで、インペラ式ショットピーニングの各種条件は、ショット径がφ０．８ｍｍ、ショット硬さが約５６０ＨＶ、ショット速度が７３ｍ／ｓ、ショット距離が３５０ｍｍ、カバレージが約３００％、アークハイトが約０．５ｍｍＡである。

【００３９】（比較例１）油冷後のままの平滑材を試料３とする。

【００４０】試料１～３について残留応力の測定を行った。各試料の残留応力分布、即ち表面からの深さ（μｍ）と残留応力（ＭＰａ）との関係を図２に示す。

【００４１】ここで、残留応力の測定は、微小部Ｘ線測定機を用いて行った。内部の残留応力は、各試料をウインドウ法でマスキングした後、電解研磨で所定の深さまで研磨して測定した。各試料における残留応力の測定位置は、試料１において歪みゲージ１６を取付けた位置とし、また、Ｘ線応力測定の条件は、Ｘ線としてＣｒ－K_α線を用い、入射Ｘ線ビームの径は２ｍｍ、応力の算定は$2\theta-\sin^2\psi$法（ψ＝０°，１０°，２０°，３０°，４０°）を用いた。

【００４２】図２に示すように、浸炭窒化焼入れのままである試料３においては、板材表面の残留応力（σ_{rs}）は約５０ＭＰａ、即ち引張残留応力であった。また、最大圧縮残留応力（σ_{rmax}）は約－４００ＭＰａであり、その発生位置は表面からの深さが約４１０μｍの位置であった。

【００４３】試料３にインペラ式ショットピーニングにより表面改質処理を施してなる試料２においては、σ_{rmax}は－８６９ＭＰａであり、その発生位置は表面からの深さが約２０μｍの位置であった。また、板材表面のσ_{rs}は－６２８ＭＰａであった。

【００４４】これに対して、試料３に予応力＋サブゼロ処理により表面改質処理を施してなる試料１においては、σ_{rmax}の発生位置は板材表面であり、σ_{rmax}は－１１７９ＭＰａであった。

【００４５】各試料について曲げ疲労強度を測定したところ、板材表面にσ_{rmax}が発生していた試料１の曲げ疲労強度は、試料１，２の曲げ疲労強度と比較して著しく向上していた。

【００４６】次に、試料１～３を微小部Ｘ線測定機を用いて観察し、残留オーステナイト量の測定を行った。各試料の残留オーステナイトの分布、即ち板材表面からの深さ（μｍ）と残留オーステナイト量（容量％）との関係を図３に示す。

【００４７】図３に示すように、浸炭窒化焼入れのままである試料３においては、板材表面の残留オーステナイト（γ_{Rs}）量は２７．６ｗｔ％、最大残留オーステナイト（γ_{Rmax}）量は４７．４ｗｔ％であった。

【００４８】試料２においては、γ_{Rs}量は２２．２ｗｔ％、γ_{Rmax}量は３９．６ｗｔ％であった。このことから、インペラ式ショットピーニングによる表面改質処理を施しても、γ_{Rs}量はあまり減少しないことがわかる。

【００４９】これに対して、試料１においては、γ_{Rs}量は１４．４ｗｔ％、γ_{Rmax}量は１８．３ｗｔ％であった。このことから、予応力＋サブゼロ処理による表面改質処理を施すことで、γ_{Rs}量が大きく減少する、即ちマルテンサイト相の生成量が多いことがわかる。その結果、試料１においては、大きな圧縮残留応力が導入されることになる。

【００５０】

【発明の効果】以上要するに本発明によれば、次のような優れた効果を発揮する。

（１）　焼入れ後の鋼材に引張応力を付与した状態でサブゼロ処理を行うことで、鋼材の表面に最大圧縮残留応力を導入することができる。

（２）　（１）により、疲労強度に優れた鋼材を得るこ

とができる。

【図面の簡単な説明】

【図１】第１の実施の形態に係る鋼材の表面改質方法で、焼入れ鋼材に引張応力を付与する方法を示す断面概略図である。

【図２】鋼材の表面からの深さと残留応力との関係を示す図である。

【図３】鋼材の表面からの深さと残留オーステナイト量との関係を示す図である。

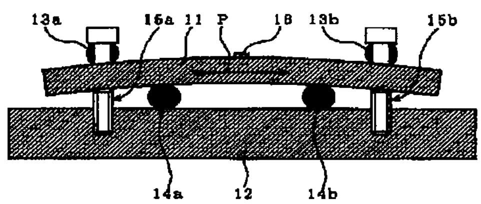
【図４】第２の実施の形態に係る鋼材の表面改質方法を説明するための断面概略図である。

【符号の説明】

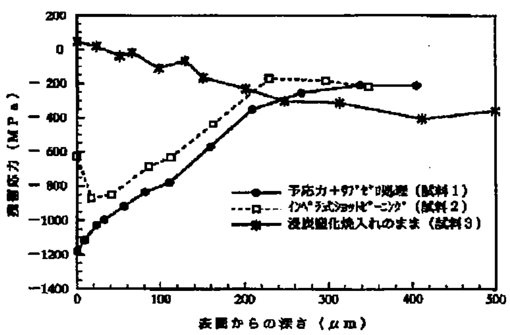
１１　板材（鋼材）

Ｐ　引張応力

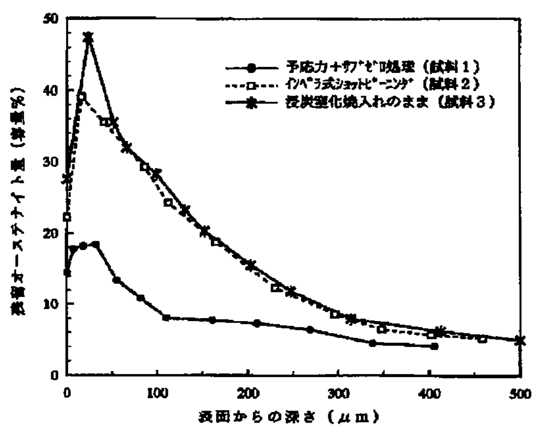
【図１】



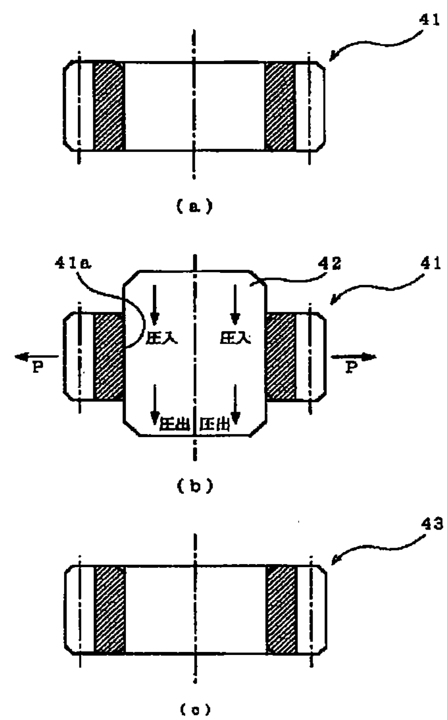
【図２】



【図３】



【図４】



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